Report No: TSD/01 dated Nov-2005

TITLE:	**METALLURGICAL & TECHNOLOGICAL ASPECTS OF WELD SURFACING**

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Abstract

Weld surfacing is a fusion-welding related technique used to restore dimensions of worn surfaces of a component, or to apply a layer of alloy on the original job to achieve characteristic properties like; better resistance to impact, abrasion, wear or corrosion. Among the major benefits accrued from surfacing; enhanced life, rebuilding of worn parts at a fractional price of the replacement cost, convenience for localized modification, reduction in break down time and enhancing efficiency at work place are to name a few. The expected economic benefit from these applications is the driving force for the feasibility of selectively applying surfacing material. Weld surfacing of a new component or reclamation work is quite complex and depends on the choice of process, selection of material, methodology of work, etc. In this article, an effort has been made to explain these factors in details to assist for a judicial decision and help for a successful weld surfacing application.

1.0 Introduction:

Every manufacturing plant encounters wearing out of their mechanical components during service. Such phenomena result into a substantial maintenance effort along with their consequential effects on production interruptions & thereby enormous losses. Surfacing is therefore one technique that can have a valuable contribution towards improvement in working and reduction of losses. The science and technology shall thus be correctly implemented to alleviate the problem.

Although surface coatings may be applied in a variety of processes, welding is considered as the principal method due to its ease of operation, higher rate of deposition & economy. Almost all welding processes can be used for the surfacing applications. Still, choice of process is dependent on size, shape, base metal composition and economics.

The prime use of weld surfacing is the reclamation of worn out or damaged components which would otherwise be scrapped. Generally, attention is given simply to restore the original dimensions with a compatible surfacing material rather than attempting to improve the service performance of the component. This may be a practice to quickly overcome the difficulty or the engineer is unable to get a new replacement within a reasonable period of time. With a little more thought in the work about its end application, the project engineer could have reclaim the job quickly, economically and at the same time with improved service performance significantly.

2.0 Assessment & history of job

Before undergoing for weld surfacing of a component, it is essential to know about the job and the associated working environment wherein the component has suffered or going to suffer in service. The reason for surface damage, erosion, wear, corrosion may provide a better understanding of the whole process and thereby may give a clue to the scope of improvement in operating conditions.

For surfacing of new component or reclamation of any existing component, the salient points shall be recorded are as follows.

1. Material of the component presently being used
2. Metallurgical implications of the existing design like; pre or post-weld heat treatment, chemical composition, carbon equivalent, etc.
3. Compatibility of base metal & surfacing metal
4. Operating conditions
5. Actual, anticipated & minimum life of the component
6. Associated cost from surface deterioration
7. Cost of surfacing
8. Cost of a new component

From the above input, a cost benefit analysis is done and sometimes a full-scale test is carried out and decision is taken.

Prior to decide for a surfacing work, the aspects which are to be looked into are - the available processes in the shop floor, the form/ size of surfacing alloys, approximate coating quantity & deposition rate.

3.0 Consideration on base metal

The chemical composition of the base metal is considered to be of prime importance in any surfacing application. For thick & high hardenability material, there remains a chance of fissuring or cracking on the first layer of the hard-surfacing deposits. Preheating of the job and maintaining a suitable temperature in-between the passes may thus be effective.

If the job has any previous surface treatment or surfacing had been done earlier needs to be known prior to the operation. Generally, the earlier hard-faced surface is removed before the new surface-coat is applied on the job.

Sometimes there is a chance of distortion of the job while heating due to release of residual stresses. If the dimension of the finished component is critical, such stresses are required to be removed for achieving a dimensionally stable component.

4.0 Selection of process

Since almost all commonly known welding processes may be used for surfacing therefore, processes available on the shop floor generally limit the options. Only in few cases of surfacing, deposition is restricted with one or two processes.

Common welding processes generally adopted for weld surfacing are -

a) Oxy-acetylene gas welding

b) Manual metal arc welding

c) Gas tungsten arc welding

d) Flux cored arc welding

e) Submerged arc welding

The shape & size of the component, intricacies of the surfacing location, metallurgical factors (heat input, cooling rate, etc.) and the estimated quantity of deposit also control the process selection.

5.0 Classification of consumables

Only a few of the hard surfacing consumables are classified under the available standards. Many of them available in the market are of manufacturer's design based on the class & type of service.

The classifications of surfacing consumables under AWS SFA 5.13 (Specification for surfacing electrodes for shielded metal arc welding) and AWS SFA 5.21 (Specification for bare electrodes and rods for surfacing) are categorized into five different classes (section 5.1 to 5.5) and are briefly described below.

5.1 Iron Base Filler Wires & Electrodes

5.1.1 Low alloy filler metals & electrodes (ERFe1& ERFe2 and EFe1 & EFe2)

- Deposits machining grade, crack free weld metal on carbon & low alloy steel.
- Deposited hardness lies between 25-50 HRC.
- Typical applications include – repair of worn machinery components and a buffer layer prior to deposit more abrasion-resistant material.

5.1.2 Medium alloy filler metals & electrodes (ERFe3 and EFe3)

- Deposits air-hardening type steel with hardness between 55-60 HRC.
- With suitable preheat & inter-pass temperature, crack-free weld can be made.
- Machining is done by grinding.
- Typical applications include – overlay surfaces on edges of tools & dies, metal-to-metal wear applications and where high impact resistance property is required.

5.1.3 Medium alloy electrodes (EFe4)

- Deposits a high carbon (1.0-2.0%) medium alloy relatively brittle weld metal.
- The deposit is prone to crack and is difficult to machine if cooled very fast.
- Typical applications include – reclamation of cast iron machinery parts.

5.1.4 Medium alloy filler metals & electrodes (ERFe5 and EFe5)

- Air-hardening cold work type tool steel weld deposit having hardness between 50-55 HRC.

- Can be machinable after annealing.
- Typical applications include – reclamation of shafts, brake drums and for those areas involving high compressive strength with moderate abrasion and meta-to metal wear.

5.1.5 High alloy filler metals & electrodes (ERFe6 and EFe6)

- Weld deposit is high-speed tool steel with a hardness of 60 HRC or higher.
- Retains hardness and metal-to-metal wear resistance up to 593°C.
- Air-hardening deposits having machinability only after annealing.
- Typical applications include – shear blades, trimming dies, punching dies, etc.

5.1.6 High alloy electrodes (EFe7)

- A high-carbon weld deposit with high abrasion resistance and moderate impact resistance.
- Air-hardening type weld metal with ~60 HRC hardness.
- Stress-relief cracks appear on the weld-surfaced layer.
- Typical applications include – cement chutes, fan blades, bulldozer blades and earthmoving components and other areas where low stress high abrasion resistance properties are desired..

5.1.7 High alloy filler metals (ERFe8)

- A complex carbide deposit in a martensitic matrix.
- Weld metal hardness is ~54-60 HRC and is finished by grinding only.
- Typical applications include – overlay surfaces subjected to moderate abrasion with high impact, machine tools & components against sliding metal-to-metal wear.

5.1.8 Austenitic Manganese Grades Filler Wires & Electrodes (EFeMn & ERFeMn)

- Weld metal contains 14% manganese with chromium, molybdenum & vanadium.
- Most appropriate in those areas dealing with heavy impact, where the work hardening quality of the deposit becomes a major concern.

♦ The normal hardness of these weld deposits is 170-230 BHN and after work hardening it goes up to 450-500 BHN.

♦ Not suitable for elevated temperature applications. May cause embrittlement if re-heated above 250-315°C. Thus often during welding, the job is kept under water to avoid this undesirable phenomenon.

♦ Heat Treatment - weld deposit is usually not heat-treated. However, if the weld undergoes embrittlement due to multi-layer deposit, water quenching from 1010°C after holding for 2 hours restore the toughness.

♦ Not resistant to oxidation or corrosion.

♦ Moderate resistant to high & low stress abrasion.

♦ Machining is difficult and shall be done by grinding.

♦ Typical applications include - Jaw crusher, railway frogs & crossings, power shovel parts, etc.

5.1.9 Austenitic High Chromium Iron Filler Wires & Electrodes (ERFeMnCr & EFeMnCr)

♦ FeMnCr deposits have similar characteristics of austenitic manganese deposits.

♦ High chromium makes the weld stainless.

♦ Typical applications include – rebuilding or repair of components made from hadfield manganese steel, joining between austenitic manganese steel and also with carbon steel and parts subject to both wear and impact.

5.1.10 Austenitic High Carbon High Chromium Iron Filler Wires & Electrodes (ERFeCr & EFeCr)

♦ Essentially C-Mn-Cr-Mo type surfacing consumables and some grades are with addition of V and W.

♦ FeCr-A1A and FeCr-A4 class consist of hard chromium carbides dispersed in austenite matrix. The deposited weld is ground finish and has stress relief checks. The A1A class provides better impact resistance but has slightly less abrasion resistance than A4 class.

♦ FeCr-A2 class consists of titanium carbides dispersed in austenite matrix. Machinable by grinding and limited to three layers deposit only. Suitable to abrasion and moderate impact.

♦ FeCr-A3 class consists of hard chromium carbides dispersed in martensitic matrix. The weld is suitable for low stress scratching abrasion with low impact.

♦ FeCr-A5 class consists of hard chromium carbides dispersed in austenite matrix. Suitable for frictional meta-to-metal wear under low stress abrasion.

♦ FeCr-A6 and FeCr-A7 classes are higher carbon version of A5 class. The weld metal (50-60HRC) consists of hexagonal chromium carbides dispersed in austenite matrix. Suitable for low stress abrasion with moderate impact.

♦ FeCr-A8 class is the higher chromium version of A3 class. The weld metal (50-60HRC) consists of hexagonal chromium carbides dispersed in austenite matrix. The weld is applied to carbon steel alloy steel and austenitic manganese base metals.

♦ Some grades (-EX series, A9 & A10) contain complex metallic carbides of vanadium, niobium, tungsten, etc and maintain their hot hardness to 650 °C. The weld deposits have stress relief checks.

5.2 Cobalt Base Filler Wires & Electrodes (ERCoCr & ECoCr)

♦ Elevated temperature strength & retention of hardness are out-standing properties for this group. They are generally considered superior to other surfacing alloys where these properties are required above 650 °C.

♦ These filler metals content 25-33% chromium that confers oxidation resistance, 3-14 % tungsten that promotes elevated temp strength while the cobalt base gives corrosion resistance & provides a stable solid solution matrix. Carbon contributes strength & in combination with chromium, forms hard chromium carbide that provides abrasion resistance.

♦ CoCr-A deposit gives a good combination heat corrosion & oxidation resistance and higher carbon grades (Co Cr-B & CoCr-C) are suitable were greater hardness & abrasion resistance are needed but there impact resistance is not mandatory. The applications of CoCr-A deposits include reclamation of guide rolls, hot extrusion & forging dies, hot-shear blades, valve trim, etc.

- Weld metals of CoCr-E has very good strength & ductility at temperatures up to 870°C. Deposits are resistant to thermal shock and both oxidizing & reducing atmosphere.

- CoCr-F is used for automotive exhaust valves and air-cooled higher operating temperature engines. CoCr-G imparts excellent abrasion resistance under high loads. This weld metal is sensitive to cracking therefore, preheat, inter-pass & cooling rate shall be closely maintained. The weld is extensively used for reclamation of triangular drilling tools.

- The weld deposit gives 23-47 HRC for CoCr-A, 34-47 HRC for CoCr-B, 43-58 HRC for CoCr-C, 20-35 HRC for CoCr-E, 32-46 HRC for CoCr-F and 52-60 HRC for CoCr-G.

- Typical applications include - valve trim in steam engines on pump shafts & on similar applications subjected to corrosion & erosion.

5.3 Nickel Based Filler Wires & Electrodes (RNiCr and ENiCr)

- These deposits have good metal-to-metal wear resistance, good low stress scratch abrasion resistance, corrosion resistance and retention of hardness at elevated temperatures.

- NiCr deposits are oxidation resistant up to 900°C. Completely resistance to atmospheric, steam & salt spray corrosion. They are also resistant to milder acids & common corrosive chemicals.

- High carbon classification, NiCr-C has excellent resistance to low stress scratching abrasion and good galling resistance. Not recommended for high stress grinding abrasion.

- Typical applications include - seal rings, cement pump screws, valves, screw conveyor, cams, etc.

5.4 Copper Base Alloy Electrodes

♦ Used to deposit overlays & inlays for bearing corrosion resistance & wear resistance surface. Commonly ER CuAl-A2 filler metals & E CuAl-A2 electrodes are used for lower hardness (130–190 BHN) applications and RCuAl-C, RCuAl-D, RCuAl-E, ECuAl-C, ECuAl-D & ECuAl-E for higher hardness (230-290 BHN) applications.

♦ RCuSi-A & ECuSi filler metals are used primarily for corrosion resistant surfacing. These deposits are not recommended for bearing service.

♦ Copper-Tin filler metals are used for surfacing where lower hardness & corrosion resistant deposits are required. These filler metals are rarely used for wear resistant applications.

♦ Copper base filler metals are not recommended for hot hardness applications, mechanical properties deteriorate as temperature increases above 200°C.

♦ CuSn filler metals have low impact properties due to coarse grain structure & lower inherent strength of these alloys. CuZn-E deposits have very low impact values.

♦ For oxidation resistance applications CuAl filler metal is best, CuSi deposit is fair while CuSn would be comparable to that of pure Copper.

♦ Silicon Bronze (CuSi) is poor bearing alloy.

♦ CuZn-E (leaded bronze) is suitable for overlay of locomotive journal boxes. The electrode deposits porous weld metal, which helps to retain oil for additional lubrication.

♦ Machinability of all these copper alloys is good.

♦ On large sections, a preheat temperature of 150°-300°C is used to medium / high carbon steel but inter-pass temperature shall not exceed 250°C.

♦ Typical applications include - gears, cams, shaves, wear plates, dies, etc.

5. 5 Tungsten Carbide Electrodes

♦ Outstanding abrasion resistance with limited resistance to impact.

- WC and W_2C are the mixture of tungsten carbide.
- Hardness varies from 30-60 HRC.
- Typical applications include – reclamation of earth drilling tools, excavator teeth, oil drill bits, etc.

Many of the hard surfacing consumables are proprietary and customer specific, designed to suit for particular type of service requirements. Sometimes for an intended application, chemical compositions of surfacing deposits also vary depending on the manufacturer's design. A wide variety of surfacing material is available meeting to the type of processes and the end applications.

However, selection of any weld surfacing consumables depends on resistance to a particular environment (abrasive, corrosive, oxidizing, etc.), stress condition (high, low, impact, rubbing, etc.), loading condition (wet, dry, static, dynamic, etc.) and service temperature.

Apart from the perspective of end application, solid solubility (ability of one element to be dissolved in the other) of corresponding metals & surfacing material is very significant in selecting the surfacing consumables. In case of metallurgical mismatch, there may not be sufficient bonding between the two and cracking may occur in the weld/ heat affected zone.

6.0 Application & expected properties from surfacing

Prior to undergo the surfacing treatment it is very important to finalize its scope & the desirables. For an example, if appearance of fissures/ cracks is undesired, high carbon complex carbide deposition is not a right selection for that application. In a similar way, a low heat input process of surfacing shall be selected if dilution with base metal is not desirable.

In general, high heat input in weld surfacing applications is undesirable. It promotes coarse grain formation in the heat-affected zone of base metal and result in hard & brittle martensitic microstructure in ferritic steel. It also enhances the propensity of dilution with the base metal. More heat input along with higher inter-pass temperature might result precipitation & formation of undesired phases like, carbides, sigma, etc. while surfacing with stainless steel consumables.

The properties like; hardness, corrosion resistance, microstructure of deposit, degree of allowable distortion, residual stresses, post-weld machining, etc shall be taken into account while designing the job.

The major applications of weld surfacing can be considered as-

a) Internal cladding of vessels with stainless steel, inconel, etc.
b) External cladding of rolls with stainless steels or hardfacing alloys.
c) Reclamation of dredger buckets & teeth with FeMn/ FeMnCr alloys.
d) Re-building hot-working tools & dies with cobalt/ tungsten alloyed alloy.
e) Depositing high carbon/ high chromium-iron alloys for good abrasion & corrosion resistance.
f) Build up of worn parts.
g) Depositing copper based materials for good resistance to adhesive wear, non-seizing properties in combination with corrosion resistance for bearings, gears, propellers, etc.
h) Deposition of wear-resistant metals.
i) Re-building high-speed tools with suitable high C, Cr, Mo, W, V alloys.
j) Surfacing against metal-to-metal wear and elevated temperature applications with Ni-based alloys.

‘Weld filling’ of cracks/ porosities are always avoided. Such repairs may propagate the defect further or may cause formation of under-bead cracks resulting in catastrophic failure in service.

7.0 Selection of acceptable level of quality

The common defects those are encountered in the surfacing application are – porosities, micro-fissures, cracks, slag inclusions, lifting of deposits, etc. Though defect in any form is undesired, presence of defects may not necessarily adversely affect the performance of the component. Examples of few defects those are not tolerated in some applications are-

a) Contraction cracks/ porosities are not tolerated for valve seats, corrosion resistance, fatigue loading and fluid erosion applications.

b) Micro-fissures/ grinding cracks are avoided for applications involving high mechanical stresses or vibratory type loading.

c) Under-bead cracks may occur in the heat-affected zone of the base metal depending on base metal composition and bonding between the surface layer & base metal. Such defects may cause/ promote lifting of hard-surfaced deposits due to improper bonding with the base metal.

Considering the application, porosity can be accepted depending on the concentration (few specks to spongy metal), distribution and location of appearance of the defect.

8.0 Summary

a) The value of wear-protection i.e., surfacing is best related to & measured in terms of plant availability.

b) It is fundamental to understand the working environment and wear mechanism prior to select any appropriate type of welding consumable or process.

c) Even for the best-selected alloy, sticking to the metallurgical requirements (preheat, inter-pass temperature, heat input, post weld heat treatment, etc) is indispensable. Weld bead & heat affected zone microstructures influence a lot to achieve the expected service life of the component.

d) A well-documented procedure shall be followed for the surfacing job with an account of their quality expectations.

e) The effect of the defects to impair the service performance shall be considered as the scale for their quality acceptance.

Acknowledgements

The authors gratefully acknowledge the Management of D & H Secheron, Indore to encourage & publish this work.